Appendix G-1
Guidance for Designing Biofiltration Swales

Biofiltration swales treat runoff by filtering the runoff from frequent, small storms. Runoff through the swale must be slow enough to allow particulates to settle out. Some adsorption and uptake of dissolved pollutants also occurs as described in BMP Fact Sheet No. 38 (see Section 5.3.) To be effective, the following design guidelines should be met:

1. The swale should have side slopes of at least 3:1 run over rise and provide at least one foot of freeboard. The facility must be able to convey the peak flow from the drainage basin for the 2-year, 24-hour design storm. The maximum depth of flow should not exceed 0.25 feet and the velocity should not exceed 1.5 fps. A Mannings "n" of 0.35 should be used to calculate the flow depth and velocity.

2. The design length of the swale shall be 200 feet for each 5 acres of impervious surface in the drainage basin.

The attached pages contain an excerpt from "Biofiltration Swale Performance, Recommendations and Design Considerations", published by the Municipality of Seattle and Dr. Richard Horner in October 1992. The information includes criteria and guidelines in general, for design and installation, and for operation and maintenance. Also included as an example design procedure.

The Seattle/Horner methodology specifies the use of the 6-month, 24-hour design storm. However, as stated above, the 2-year, 24-hour event may be more appropriate; consult the local permitting authority.

SECTION 7

RECOMMENDATIONS

In addition to the studies presented in Sections 5 and 6 of this report, members of the Biofiltration Project team and others we have consulted have acquired insights in other aspects of stormwater management associated with biofiltration swales. This information is presented here under the following categories: Institutional and planning, design and installation, operation and maintenance, and areas for further study. In addition to the discussions and recommendations given here, the Application Guide prepared in the Phase I report is updated to include these recommendations and is presented in Appendix G.

PLANNING CONSIDERATIONS

Landscaping

The relationship between biofiltration swales and landscaping, in terms of satisfying jurisdictional requirements, is purely a matter of local governmental discretion. However, there is no insurmountable constraint preventing the merging of the two uses. This said, there are several practical considerations to ensure such a melding does not compromise water quality objectives.

Swale planting. First, a word should be said about the planting of the swale itself. Biofiltration swales, otherwise known as grassy swales, typically rely on a dense planting of grass to provide the filtering mechanism responsible for water quality treatment. Most grasses tend to be very finely divided, with densely spaced blades. Pollutant removal effectiveness is related both to the density and stiffness of the blades, providing the "scrub brush" effect, and to the amount of surface per unit area provided by the individual blades. Few other herbaceous plants present the same features of finely divided and densely spaced leaf or stem surfaces.

In addition, grass has a unique ability to grow up through thin deposits of sediment or sand. Beach grasses are a good example, showing adaptation to a shifting sand environment by continuing to grow as lower stems and blades are covered with sand. The ability to grow up through a certain amount of sediment is highly desirable for water quality treatment. Besides maintaining blade density, it stabilizes the deposited sediment, preventing it from being re-suspended and washed out of the swale. Some grass species are better at dealing with deposited sediment than others, and there is, of course, a limit to how fast any grass can grow in response to burying.

Thus for typical biofiltration swales, grass is by far the most effective choice of plant material. A grass seed mix used successfully in Mountlake Terrace, Washington is given below:

• Tall fescue	67 percent
• Seaside bentgrass	16 percent
• Meadow foxtail	9 percent
• Alsike clover	6 percent
• Marshfield big trefoil	1 percent
• Inert matter	1.5 percent
• Weed seed	0.5 percent

However, swales are often positioned in shady locations, or experience self-shading due to their geometry and orientation. In these cases, as in all lawns, moss becomes a problem. Although not as finely divided as grass, moss does provide a high degree of surface area. In addition, several researchers have found that moss is a highly effective cation-exchanger, able to remove even low concentrations of metals from water (Low & Lee, 1991, Lee & Low, 1989, Ruhling & Tyler, 1970). Growing with grass, the moss tends to be supported upright by the grass stems. However, most moss species have less rigidity than grass, and when inundated, tend to lie flat rather than maintain an upright posture. Overall, moss in grassy swales is probably a benefit if grass densities are relatively high, but can be a problem if grass densities are too low, reducing the "scrub brush" effect of the vegetation.

Grass (other than reed canarygrass) will not grow under conditions of permanent inundation. For swales established on sites that intercept groundwater or with little or no slope to provide for good drainage, use of wetland vegetation is an acceptable planting alternative. However, the same considerations apply. The more finely divided the plant material in the water contact zone, the more effective its ability to provide treatment. Although cattails are inexpensive and easy to grow, they are discouraged for use in biofiltration swales for two reasons. First, in disturbed environments cattails tend to be invasive. Limiting their spread by limiting use is desirable, particularly if sensitive wetlands occur downstream from the swale location. Secondly, cattail stems tend to form tight clumps. These clumps are not finely divided like grass, but have overlapping or contiguous leaves and stems, making it difficult for water to flow through the clumps. Other smaller wetland species, such as *Juncus* (rush), *Eleocharis* (spikerush) or *Scirpus* (bulrush) may provide better filtration surface per unit area, provided the plants are healthy and produce vigorous growth.

Experience with wetland plants in a constructed wetland at Metro's South Transit Base has shown that the species listed below tend to be fairly finely divided and relatively resilient. They grew well even though subjected to fluctuating water levels and inundation stresses during typical storm events (Metro, unpublished data).

- *Juncus tenuis* (rush)
- *Juncus ensifolius* (dagger rush)
- *Scirpus microcarpus* (small-fruited bulrush)
- *Eleocharis* (spikerush)
- *Sparganium euycarpum* (burreed)

Weedy and invasive species such as cattail, purple loosestrife, reed canarygrass and giant reed (*Phragmites*) should be avoided.

Adjacent plantings. Woody or shrubby vegetation is not appropriate in the active treatment area of a biofiltration swale. However, in the area above the normal treatment area, that is, beginning with the portion of the side slopes designed as freeboard to pass larger storm flows, other kinds of landscaping material may be appropriate. The most important considerations for integrating other landscape materials without compromising the water quality objectives of the swale are shading and slope stabilization. A nonaggressive ground cover material such as *Hypericum* (St. John's wort), *Ajuga* (bugleweed) or *Vinca* (periwinkle) could be placed above the grassed treatment area of the swale without ill effect, provided the ground cover was dense enough to prevent any transport of sediment from the upper slope into the swale. Barrier shrubs, such as barberry, if continuous around the swale perimeter, could be effective in keeping out dogs.

Trees or shrubs that mature to provide a dense canopy will shade the swale. Since most grass species grow best in full sun, dense shade should be avoided. If shaded for too much of the day, grass will not grow densely enough to provide good filtration benefits. The City of Mountlake Terrace requires a 20-foot spacing of trees near swales to avoid this problem (Khan, personal communication). In addition, leaf or needle drop can contribute unwanted nutrients into the swale, can create debris jams which interfere with the evenness of water flow through the swale, clog inlet and outlet areas, and smother or even kill the grass.

Evergreen trees or shrubs, either coniferous or deciduous, planted on the east or north sides of swales could avoid most of the drawbacks mentioned above. Even so, shedding of pollen cones from coniferous trees was observed to cause minor blockage and channelization problems in the study swale in Mountlake Terrace.

Another consideration in establishing trees or shrubs in proximity to a biofiltration swale is that of stabilizing the soil in the planting beds. Often landscaped areas are mounded, with the soil surface mulched with bark. This is a particularly undesirable situation from the standpoint of good swale maintenance. Bark and mulch on mounded surfaces will inevitably be carried downstream into the swale, causing excess sedimentation, clogging of inlet or outlet areas, and unevenness in the swale bottom leading to channelized flow. The introduction of fertilizers and even pesticides and herbicides can also be problems.

If landscape beds are placed near swales, the beds themselves should be flat rather than mounded. Beds slightly lower than the ground surface are even more desirable, particularly if mulch or bark is to be applied. Bed edging can also help prevent soil from leaving the beds and being washed into the swale.

Animal manures should not be placed in the soil mix used within the swale proper. The bacteria in such a soil mix can stay alive and grow in the soil, often for long periods of time, causing water quality problems when carried downstream.

Treatment Trains

Treatment train is a term used to describe a situation when two or more treatment control devices are placed together at a site to remove pollutants from stormwater. Often a distinction is made between a treatment control device and a source control device. A treatment device, often a physical structure, is designed and constructed specifically to remove pollutants already in the water. Source control devices are prevention techniques used at the point of generation of pollutants to prevent their entry into stormwater. Source control devices could include beams and roofs erected to prevent rainwater from coming into contact with pollutants, or shut-off valves to contain spills before they leave a site.

In selecting a stormwater treatment system, several factors should be considered. The stormwater requirements of the political jurisdiction in which the business or property is located are paramount. Many jurisdictions have requirements for control of the rate of discharge (or peak runoff rate) from new or redevelopment. This control is usually accomplished by detention of the flow, discharging at a controlled release rate through an orifice (small opening). Some structures that are used for detention can also be used for stormwater treatment provided that they are properly designed for this purpose. An example is a wet detention pond which provides stormwater storage as well as water quality treatment if properly designed and maintained.

In addition, the type of land use and the potential pollutants that will be generated should be considered in determining stormwater treatment requirements. With some land uses, more than one treatment method may be needed. For example, if stormwater runoff is expected to contain high concentrations of oil, it may be necessary to use an oil/water separator to pretreat the water before it enters other treatment devices. Many jurisdictions require pretreatment in the form of solids removal or spill control by providing catch basins or gravity oil/water separators. These pretreatment measures are often used in conjunction with detention and water quality treatment devices.

In addition to grassy swales, other types of stormwater treatment methods include soil infiltration, grassed filter strips, constructed wetlands, wet detention basins, extended dry detention basins, oil/water separators (spill control catch basins, American Petroleum Institute (API) separators, and coalescing plate interceptors (CPI)).

Placement of treatment devices is also an important consideration when used in conjunction with a grassy swale. It is important to protect the vegetation in the swale against heavy loads of some pollutants like oil and grease and sediments. It may be necessary to place an oil/water separator or a sediment trap upstream from the swale. A swale may precede or follow a flow control or detention facility, but there are advantages to having the swale follow the detention pond or vault. Placing the swale downstream from a detention facility minimizes the likelihood of swale erosion. Because the detention facility will hold high flows and discharge them at a controlled rate, more of the flow from large storms events could be treated by this arrangement.

A creative placement alternative is to nest a circular grassy swale around the inner circumference of a dry detention pond. This arrangement allows for water quality treatment of low storm flows and detention of high flows within the same facility, maximizing the use of land devoted to water quality protection.

Monitoring Considerations

Often jurisdictions wish to have assurances that swales are functioning as intended and require monitoring. At other times, jurisdictions themselves may want to monitor swale performance for their own information. If monitoring may be required, jurisdictions should make these expectations clear before facilities are designed. Modifying swales for monitoring is not a casual affair. The equipment required to do flow-proportional monitoring is bulky, and flow monitoring usually requires a weir of some type (see Section 5). Manholes or catch basins may sometimes be provided at one or both ends of a swale, and may provide convenient places to sample.

Another consideration is that access to the swale should be stipulated as part of a permanent maintenance, inspection or access easement so that equipment can be serviced and samples collected. For adequate monitoring, this access is usually required well into the occupancy phase of a project, often a more difficult situation than access during construction.

DESIGN AND INSTALLATION

The effectiveness of a biofiltration swale depends largely on the accuracy of design and installation. The swale design approach in the Phase I report was first advanced by Chow (1959) for water conveyance applications and adapted or modified by others. It consists of two steps: First, designing for conveyance capacity of the swale lined with vegetative cover; and secondly, designing for channel stability to minimize erosion (Horner, 1988). This approach emphasizes the hydraulic conveyance capacity of swales rather than the water residence time. Because pollutant removal occurs as a result of sedimentation, filtration, adsorption, and other surface processes, it is logical that the emphasis on hydraulic residence time might result in optimizing swale performance.

Hydraulic residence time of a biofiltration swale depends on various components such as geometry, hydraulics, hydrology, soil type and type of vegetation. The following three design elements should be considered when constructing an efficient biofiltration system.

Hydraulics

Open channel hydraulics is one important consideration for designing a biofiltration swale. Hydraulic design of engineered swales for stormwater treatment is based on several variables, including the maximum velocity, design flow rate, depth of flow, and the channel roughness factor. The selection of proper design variables is based on several factors including hydrology, vegetation, soil type, and the goals of the treatment. The following recommendations on hydraulic design components are derived from this study.

Maximum design velocity. Geometric dimensions of most engineered biofiltration swales are designed by using Manning's Velocity Equation. A maximum permissible velocity of flow is selected to limit channel erosion and to provide a reasonable hydraulic residence time. Based on the slopes, soil types, and vegetation, a wide range of maximum allowable velocities (1.5 feet per second to 8 feet per second) have been used in earlier studies. As a part of this study, it was observed that grass (approximately 12 inches) on the bottom of the swale was flattened at velocities of about 0.9 feet per second. Flow channelization on the swale bottom accelerated with the increased degree of grass bending. Horner recommended that the design velocity be limited to a maximum of 1.5 feet per second. However, this study demonstrated that the maximum velocity should not exceed 0.9 feet per second to prevent exceeding the treatment capability of the swale.

Manning's n. A wide variety of vegetation types, heights, and densities have been used for biofiltration swales. These vegetation characteristics control the flow retardant and filtration capabilities of biofiltration swales. Manning's n is the channel roughness factor, which incorporates vegetation characteristics into the swale design. Even though many tables have been published for selecting Manning's n, the proper selection of n value is difficult as well as controversial among designers (Horner, 1988, *Guidebook Water Quality Swales*, 1990). An objective of this study was to measure Manning's n for a particular grass-lined swale. Section 6 contains the detailed description of the Manning's n determination. From results of this study, it is recommended that a Manning's n of 0.20 should be the minimum n value used for designing grassy swales intended for water quality treatment purposes. It may be that for situations in which swales are infrequently mowed, such as rural roads, a higher Manning's n value (0.235 is suggested) should be used for design. It may also be true that for denser grass, a higher Manning's n value may be appropriate for design. However, the study is not able to make recommendations for this denser grass situation.

Flow spreading and channelization. Hydraulic design of a biofiltration swale assumes that the flow will distribute evenly across the channel bottom. Flow channelization on the swale bottom reduces the effectiveness of biofilters by generating excessive velocities and scouring of the channel bottom and reducing contact with the vegetation. Swale design should incorporate a flow spreading device at the inlet. Flow spreading can be accomplished with various structures such as a shallow weir across the channel bottom, a stilling basin, perforated pipe, or other means. The flow spreader should be designed to provide a uniform flow distribution across the swale bottom. It should include a sediment clean-out area and must have low maintenance requirements.

To minimize flow channelization, it is imperative that the swale bottom is first, entirely smooth with uniform longitudinal slope, then covered with uniformly dense vegetation, and finally free from deposited sediments and debris. Swales with relatively wider bottoms are susceptible to more flow channelization. Flow channelization can be reduced by installing check dams at reasonable intervals; however, check dams make mowing more time consuming.

For best performance, check dams should be have a level upper surface rather than be made of rip-rap.

Flow bypass. Design flow rates are often established by local regulations. It was recommended in the Phase I report that the design flow rate for biofiltration swales should be estimated from the 2-year, 24-hour storm event. According to Horner (1988), this duration adequately characterizes local precipitation and represents the typical antecedent conditions prevalent in this region for most situations. Swales are designed to either convey or to bypass high flows (such as flows greater than those from the 2-year, 24-hour storm). If a swale must convey high flows, consideration should be given to the control of channel erosion and destruction of vegetation, and a stability analysis must be performed.

Flow can be bypassed by installing a pipe parallel to the swale and a flow regulating device inside the inlet structure. High flow bypasses may be of two types. During some storm events pollutants are more concentrated in the "first flush." Where space is a constraint, biofiltration swales could be designed for treating stormwater pollutants only from the initial portion of the storm. This approach would require bypassing stormwater flow around the swales during the higher portions of the flow. More typically, swale bypasses are designed to treat the design flow throughout the storm event, bypassing only the flows in excess of the design flow.

There are advantages and disadvantages to including a flow bypassing structure in the swale design. Bypassing high flows has the advantage of avoiding the carry-in of leaves, litter and heavy sediment loads dislodged by large storm events which can cause flow channelization and interfere with treatment effectiveness. High flows have also been observed to cause flattening of swale grasses for several days following a storm event, particularly if the grass is long. Flattened grass would be less effective in removing pollutants from subsequent storm events. Additionally, a bypass would allow diversion of flows in other situations, such as during swale maintenance, regrading, and vegetation establishment.

It should be noted that some of the problems experienced when high flows are transported through swales can be avoided if swales are placed after detention ponds or flow control vaults.

The disadvantage of a flow bypass is that it is more expensive. In addition to the space for the swale, additional cost for the piping and control device is necessary. However, additional space for the bypass is often not needed, as the piping can be installed within the sides of the swale, depending on the elevation required.

Hydraulic Residence Time

Based on observations made during this study, a residence time of 9 minutes which was associated with the 200-foot swale configuration was found to result in good removals of particulate pollutants, including metals, oil and grease and TPH. An attempt was made to determine an optimum residence time. However, due to an insufficient spread in the data, no reliable relationship between pollutant removal and residence time was able to be derived. There was some indication, however, that the lower residence times observed, between 4 and 5 minutes, were insufficient to assure good pollutant removal in storms with pronounced peaks, but still well below the design storm flow. Until more data are available, it is recommended that a minimum residence time of 9 minutes be used for swale design. In no case should residence time be less than 5 minutes.

Base Flow

If longitudinal slope is too flat (less than 2 percent) or if base flow is present in the swale, standing water can become a problem. With the exception of reed canarygrass, an invasive and undesirable species, grass will not grow in water-logged soils. In cases where high water tables, slight slopes or winter base flows are realities on site, use of a finely-divided wetland vegetation is recommended rather than grass. Please see the previous paragraphs on landscaping for more information.

Geometry

Natural grass-lined swales or ditches can be found in various lengths, sizes, shapes, and slopes. Most common swale cross-sections are rectangular, semi-parabolic, or trapezoidal. Engineered swales are often designed with trapezoidal cross-sections. Trapezoidal cross-sections are preferred because of relatively wider vegetative areas and ease of maintenance. They also avoid the sharp corners present in V-shaped and rectangular swales, and offer better stability than the vertical walls of rectangular swales.

Geometric dimensions of a swale determine its hydraulic residence time and flow characteristics. Because the water residence time and flow velocity are the most critical factors for pollutant removal, the geometric design should accommodate sufficient hydraulic residence time and allow for maximum design water velocities less than 0.9 feet per second.

The Phase I Biofiltration design guidelines are based on several assumptions:

- Minimum length of 200 feet

- Side slopes of 3 (horizontal) : 1 (vertical)
- Longitudinal slopes between 2 percent and 4 percent
- Design flow depths at least 2 inches below grass height

Design of the study swale used for this investigation was based on the above criteria, except a maximum water depth of 0.25 ft was specified rather than a design grass height. Performance of the 100-foot swale configuration in removing pollutants is discussed in Section 5. In general, the shorter length, which also had a reduced detention time, was more susceptible to the negative effects of siltation and short circuiting than the 200-foot configuration. The shorter configuration performed more poorly on average than the longer configuration, although this effect was not statistically discernible for pollutants other than iron and zinc.

Swale length requirements in some cases are a matter of local regulation. A scientific methodology for calculating effective swale length may be derived by analyzing optimum hydraulic residence time, width, slope, flow rate, and vegetation. As a part of this study, an attempt was made to derive the methodology for estimating swale dimensions by calculating the optimum hydraulic residence time. Due to insufficient data, it was not possible to derive the optimum residence time, although it was observed that a detention time of 9 minutes provided good pollutant removals (greater than 80 percent TSS). For better pollutant removals, a longer detention time is recommended.

Length. Previous studies have recommended that biofiltration swales be 200-feet-long for pollution control purposes. Results of a University of Washington study of grass-lined ditches along Interstate 5, and other wastewater treatment investigations reported an exponential pattern of metals removal (Horner, 1988). This study showed that, with the exception of iron and zinc, the performance of two swales of differing lengths, one being 200 feet, the other 100 feet, was not statistically different. However, in addition to length, the hydraulic residence time also varied. Because of the effect of reduced hydraulic residence time, seasonal differences and potential differences in the loading within the catchment area between the two swale configurations tested, a definite conclusion with regard to swale length cannot not be made.

However, there is also evidence to conclude that swale treatment area or residence times should be considered in swale design rather than relying on length alone. Using the Mountlake Terrace swale as an example, and specifying a 9-minute hydraulic residence time and an 8-foot maximum width, a minimum swale length would be about 125 feet, assuming all other geometric and vegetation conditions remained constant.

Width. The bottom width of parabolic swales varies with the amount of flow through the swale, but is fixed for trapezoidal swales, provided flow is adequately spread when introduced. A maximum bottom width selection should be based on the design flow depth to accommodate uniform sheet flow with average depth between 1 and 3 inches for maximum effectiveness. In theory, for a given hydraulic residence time, swale widths can be increased to compensate for reduced length. However, from the experience of members of the Project team, it has often been observed that relatively wide swales (those wider than 7 to 8 feet, a typical back hoe loader width (Irig, personal communication) are more susceptible to flow channelization and are less likely to have sheet flow across the swale bottom for the entire swale length. This occurs for several reasons:

- Inadequate flow spreading at the head of the swale
- The tendency for water to rechannelize if the swale bottom of trapezoidal swales is not perfectly level in cross section, as can occur when more than one blade pass is necessary to grade the bed
- The effect of obstructions such as leaves and branches in encouraging channelization
- The tendency for a "low flow" channel to develop in the swale bottom, which is then further intensified and channelized during higher flows

Although these problems can afflict swales of any width, they are a greater concern as channel widths increase and dominate more of the treatment area surface. Because of the tendency toward channelization, and given the reality of imperfect field installation, there is a practical upper limit for swale width. The maximum width allowed should consider the effectiveness of the flow spreading design used, the likelihood that swale bottom evenness can be assured and the frequency of mowing, which reduces the build-up of trash, leaves and other debris that tend to encourage channelization. For the swale studied, bottom evenness was about as good as possible with an ordinary construction crew, and care was taken to spread the flow over the entire 5-foot bottom width after it left the H-flume. Mowing was infrequent, however. Channelization of flow, particularly to the outer portions of the swale, was apparent during the velocity measurements for the Manning's n investigation, but not to the extent that it interfered with pollutant removal. It is recommended that unless the factors listed above can be dealt with adequately, swales wider than about 7 to 8 feet should be discouraged until more information about performance can be gathered. No recommendation is made at this time for situations in which ideal conditions of swale bottom levelness, flow spreading, and frequent mowing are assured.

A practical minimum swale width for trapezoidal swales should also be established for ease of maintenance. A minimum 2-foot bottom width is recommended to facilitate swale mowing with standard lawn mowers. However, narrower widths are possible if space is very constrained.

Longitudinal slopes. Earlier swale design standards indicate a wide range of longitudinal slopes, ranging between 0.05 percent and 8 percent. Increasing the longitudinal slope of a swale has the effect of increasing velocity. High velocity reduces the hydraulic residence time and increases erosion potential. On the other hand, stagnant water causes unhealthy grass and reduces the aesthetic values of grass-lined swales. The recommendation in the preliminary design criteria (Horner, 1988) that the longitudinal slope of swales should be between 2 percent and 4 percent, with 6 percent as an upper maximum slope, is reaffirmed based on experience gained in the field. An underdrain with perforated pipe should be installed when the slope of the swale is between 1 percent and 2 percent (Figure 7-1). The underdrain should be designed to drain standing water from the swale bottom.

On steep sites, swales can traverse grades to reduce their slope. If the site topography requires that the swale be steeper than 6 percent, then vertical drops (6 inches to 12 inches) of the swale bottom at a reasonable intervals (between 50 feet and 100 feet) should be added to minimize steepness of the slope. At the toe of a vertical drop, an energy dissipating and flow spreading structure should be installed. The performance of a swale is greatly influenced by its slope, so the grading must be accurate to ensure uniform longitudinal slope by eliminating humps and low spots.

Side slopes. Relatively flat-sided biofiltration swales are easier to mow than steep-sided swales. Selective landscape planting may also be incorporated on wide and flat side slopes to enhance the aesthetic value of parking lots or other areas. Furthermore, relatively flat side slopes reduce erosion potential and provide additional stormwater detention by increasing the conveyance flow area. Ideally, swale side slopes should be no steeper than 3 horizontal to 1 vertical. Sites with limited area to provide this slope may require slopes steeper than three to one, but maintenance and slope stability are concerns when the side slopes are steeper than 2 horizontal to 1 vertical. Rock walls are sometimes constructed above flat side slopes to accommodate space constraints. However, relatively tall rock walls may impose safety hazards, complicate maintenance, and present an awkward appearance.

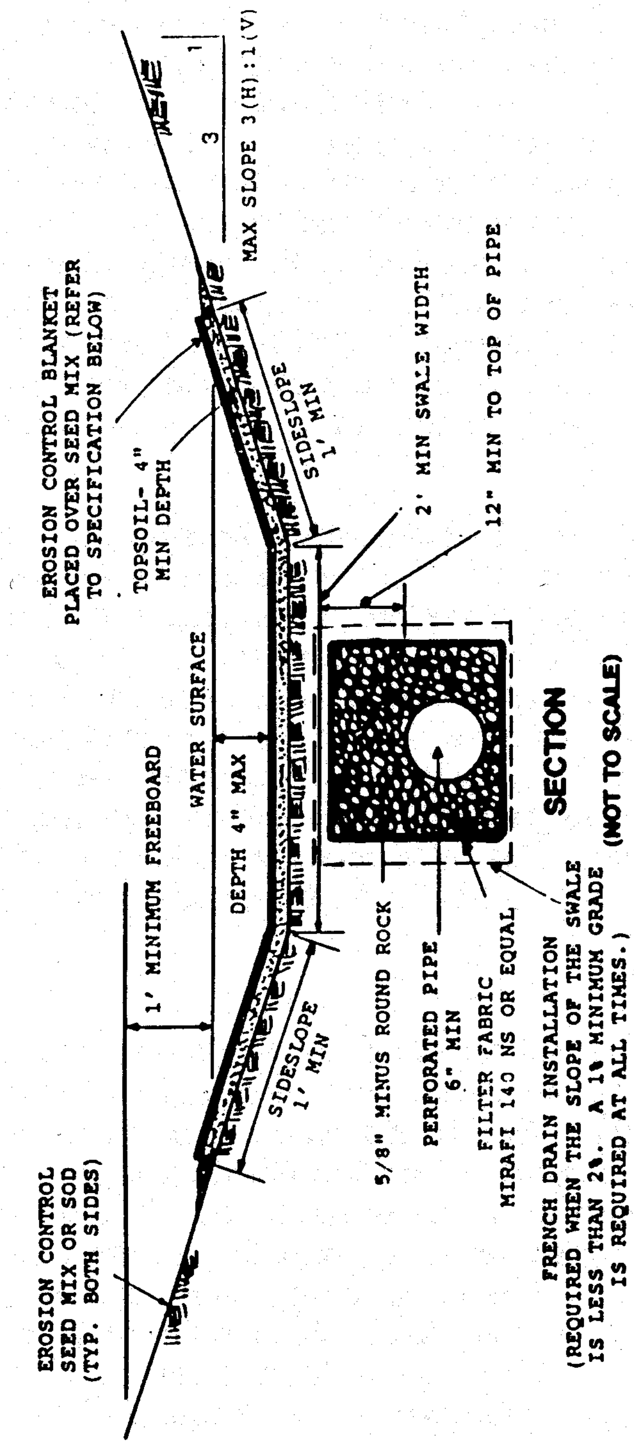


Figure 7-1. Underdrain Detail for Biofiltration Swales

Energy dissipation. Scouring of the swale near the inflow point can be a problem in grassy swales. Energy dissipation of inflow water can be achieved by installing rip-rap pads, stilling basins or other mechanisms. Rip-rap pads should be designed with swale geometry and energy generated by peak flows in mind. Often, 6- to 9-inch rock works well. However, it is important to fit the rock tightly together to avoid creation of small water pools and erosion around the rock. In general, the width of the rip-rap pad should be equal to the width of the swale bottom, with lengths between 5 and 10 feet. The flow spreader bars should be installed at the downstream end of the energy dissipater. To discourage vandalism, the rocks could be keyed into a concrete pad. Some managers recommend that rock be installed with the top flush with the bottom of the swale. However, others suggest that this can cause problems with water pooling between gaps in the rock, or that the rock can be buried due to sediment deposition.

Water depth. During the Manning's n investigations, it was observed that grass does not remain standing when water depths approached one third the height of the 12-inch grass. Therefore, the original Phase I recommendation that water depth should be at least 2 inches below the design grass height was not adequate to provide the expected biofiltration benefit. It is recommended that the design water depth be no greater than one third the height of the grass for tall grass (9 to 12 inches). It is further recommended that for mowed swales, the design water depth be no greater than one half the grass height up to a maximum water depth of 3 inches. This latter recommendation is not based on results from this research project and requires further investigation to confirm.

Soil Type Considerations

Selection of a soil type for a biofiltration swale should be based on the types of vegetation, slope of the swale, purpose of the swale, and the existing soil characteristics. Soil characteristics of a swale bottom should be conducive to grass growth. Where the longitudinal slope is less than 2 percent and the bottom is underlain with a French drain, the subgrade should be constructed with topsoil materials containing a high percentage of sand. Soils that contain large amounts of clay cause relatively low permeability and result in standing water for extended periods of time. Saturated soil causes grass to die and results in an unaesthetic appearance. Where the infiltrate from a biofiltration swale has the potential to contaminate groundwater, it is recommended that the swale bottom be sealed with clay material to protect groundwater resources. In general, for the swales located on residential and commercial development sites, use of 6 inches of the following topsoil mix is recommended:

- 50 percent to 80 percent sandy loam

- 10 percent to 20 percent clay
- 10 percent to 20 percent composted organic matter (excluding animal waste)

Topsoil must be free from materials toxic to grass growth, as well as stones and other debris and must provide adequate nutrient levels to ensure good grass growth. Onsite materials, where suitable, should be used for constructing the subgrade of biofiltration swales. Where possible, avoid using steer manures, since these are often leached into the receiving water.

OPERATION AND MAINTENANCE

During the course of monitoring the 48th Avenue W biofiltration swale, the importance of maintenance became apparent on several occasions. Areas needing particular attention include the following:

- Keeping the flow spreader even and free of leaves, rocks, and other debris
- Removing sediment from the upper portion of the swale deposited during high intensity storm events and mending channelized areas of the swale
- Removing litter, branches, rocks, and other debris which accumulate in swales
- Reseeding areas of poor grass growth
- Regular mowing

Issues related to these concerns are discussed below.

Access

In order to provide maintenance or to inspect to ensure maintenance functions are provided by the owner, access to the site is needed. Provision should be made through easements negotiated during the permitting process to require maintenance and allow access for inspection of swales. If future studies are envisioned, access for monitoring and for making modifications to the swale should also be negotiated.

Mowing

Regular mowing is important for several reasons and can affect the water quality performance of a biofiltration swale. First, biofiltration swales are often designed for a particular grass height (or water depth). If grass is mowed shorter than the design grass height, water depth may be too great relative to grass height to provide adequate biofiltration. If grass is left to grow too long, it may become lanky and grow less densely. Regular mowing encourages denser grass growth, provides for removal of vegetative debris, such as leaves and branches from swales, and avoids the tendency for formation of channels in the swale floor. If nutrient control is a treatment objective, mowing is also essential at the end of the growing season before the grass goes dormant to avoid remobilization of nutrients taken up and held by the vegetation.

In cases where nutrient removal is an objective, grass clippings should be removed from the swale and disposed of in such a way so that reentry into the receiving water is avoided. Even if nutrient control is not a primary concern, grass clippings should be removed from the swale to prevent clogging of outflow structures and to ensure flow through the swale remains even and unchannelized.

Sediment Buildup and Erosion

If swales are effective, some amount of sediment will be captured in the swale. If the rate of sediment deposition is too rapid, it can cover the grass, causing it to die, and exasperate channelization of the swale bottom. Prompt reseeding of damaged areas can prevent deterioration in effectiveness of the swale.

Before reseeding is done, the excess sediment should be removed by hand (flat-bottomed shovels work well) and grass cut short so that the bottom surface can be made as level as possible. Ideally, the same seed mix recommended for establishment of swales should be used. If possible, flow should be diverted from the swale until the grass is firmly established. Otherwise, cover the seeded areas with a high quality erosion control fabric to provide protection. It is also effective to introduce grass plugs from an area on the upper slope of the swale to further anchor the disturbed area. In general, sodding to patch damaged swale areas is not effective because of the difficulty in ensuring the sod is level with the swale bottom and the tendency for it to dry out if not watered frequently. If sod is used, it should be overseeded with a seed mix known to grow well in swale applications.

If areas are eroded, they should be filled and compacted so that the final grade is level with the bottom of the swale. Digging grass plugs from the upper slopes of the swale is preferable to filling and seeding, since the root systems already developed in the grass will do a superior job of resisting further channelization and erosion.

Byproducts and Disposal

Grass clippings. Generally, grass clippings should be removed from biofiltration swales. Upon decomposition they can contribute both nitrogen and phosphorus loads as they come in contact with stormwater. Grass can clog swale outlets, and can also collect in bunches along the swale bottom, encouraging channelization and erosion of the bottom. Unless the grass is visibly altered (for example, coated with oil or diseased) it should be disposed of in the same manner as yard waste. If the grass is visibly tainted or altered, or smells like petroleum products, it should be bagged and taken to a sanitary landfill (Burke, personal communication).

Sediment. There is much interest in whether the sediment which collects in a biofiltration swale could be a hazardous waste or a toxic material under the Model Toxics Control Act (MTCA). To be positive, chemical testing is required. Constituents to test for include total and Toxicity Characteristic Leaching Procedure (TCLP) metals (lead and zinc, perhaps others depending on land uses in the watershed) and total petroleum hydrocarbons (TPH). However, if the swale drains an area that is predominantly residential, the Seattle/King County Health Department does not typically require testing at present (Burke, personal communication).

It is possible that TPH and total metals concentrations in sediments collecting in swales could exceed the cleanup levels set by the MTCA, Chapter 173-340 WAC. More infrequently the TCLP metal concentration may be a problem. The criteria given in Table 7-1 are used by the Seattle/King County Health Department in determining if disposal of a substance of unknown origin should be specially controlled. If the substance exceeds the MTCA cleanup criteria, it should be treated to meet standards or be disposed of in a sanitary landfill. Sometimes disposal or use in controlled situations is allowed, such as for road subgrade, fill in an industrial area or a capped fill, provided no threat to health or the environment would result (Ecology, 1991). If the substance exceeds the criteria for solid waste, it must be manifested and disposed of as hazardous waste.

Table 7-1. Soil Disposal Criteria in Seattle and King County, Washington, for Selected Contaminants

Solid Waste Criteria		Clean-up Levels (MTCA)	
TPH	< 3 percent	TPH, diesel	200 mg/kg
		TPH, gasoline	100 mg/kg
Benzene TCLP	< 0.5 ppm	Benzene TCLP	0.5 mg/kg
Toluene	< 1 percent	Toluene	100 mg/km
Xylenes	< 1 percent	Xylenes	20 mg/kg
TCLP Pb	< 5 ppm	Total Pb	250 mg/kg
TCLP Cr	< 5 ppm	Total Cr	2 mg/kg
TCLP Cd	< 1 ppm	Total Cd	no level set
TCLP Cu + Ni + Zn	< 5 ppm	Total Cu	no level set
		Total Zn	no level set
		Total Ni	no level set

Note: For more information, contact the Seattle/King County Health Department, Waste Screening staff, 296-4633.

It has been observed that sediment from catch basins can exceed the MTCA cleanup level of 200 mg/kg TPH. Work currently being done by Metro shows that vegetation in a constructed wetland has succeeded in dramatically reducing soil TPH concentrations accumulating in sediments washing off a transit base (Metro, unpublished data). Further study is needed to determine whether vegetation in a biofiltration swale may have a similar effect on reducing soil TPH.

Metals are also of potential concern. Little research has been done on soil metal contamination, but Wigington et al. (1986) and Wang et al. (1981) found that in roadside soil, most of the metals concentrated in the upper 5 cm. The only leachable metal found in the Wigington study was zinc, which was suggested to come from galvanized culverts.

A study of 21 wet and extended dry detention ponds in Virginia found that the available concentrations of trace metals were significantly less (1/1000) than the toxic thresholds of federally defined hazardous waste. However, for 19 of the 21 ponds, leachable fractions from the sediment exceeded water quality standards (Dewberry & Davis, 1990). The ages of the facilities were not given, but some may approach 12 years, the life of the management requirement for BMPs.

Trash. Trash tends to blow around and collect in low spots or against high grass. Unmaintained biofiltration swales can become unsightly, particularly if located in commercial areas. Landscape architects have found that the location of a swale can make a difference in the amount of maintenance provided. If located in the front of an establishment, better upkeep is typically provided than if located in back of a facility. An ancillary benefit of regular mowing is that the accumulated trash is cut up along with the grass and removed with minimum effort.

Yard waste is a special category of debris that is sometimes dumped into biofiltration swales by nearby residents. Specific educational efforts are recommended to inform citizens about biofiltration swales and their benefits and obtain their cooperation in maintaining them in good working order.

Animal waste. Monitoring data from this study showed that fecal coliform bacteria can be introduced into grassy swales in high numbers and take a very long time to be dispelled. In order to combat fecal coliform pollution from pet waste, public education and vigorous enforcement of scoop laws are needed. As a possible measure to protect swales from the impact of pets, a continuous planting of barrier shrubs, such as barberry, could be employed. (Barberry is a densely branched, low maintenance shrub with sharp thorns plentifully distributed along the branches. Landscapers sometimes employ this plant to manage foot traffic in some areas of public landscapes.)

Pet waste should be disposed of like human waste, by flushing to a sanitary sewer or septic tank system. Pet waste is not allowed in the garbage with other solid waste. Composting of pet waste is also an acceptable option in most locations.

Institutional and Enforcement Considerations

Operation and maintenance is critical to the effective performance of a biofiltration swale. It is important that jurisdictions be able to assure maintenance for swales they require to be installed. If no assurance of long term maintenance is identified, it may be advisable to choose another type of water quality treatment, such as a wet detention pond or constructed wetland, which requires less maintenance.

Possible approaches to maintenance include requiring a construction maintenance bond, maintenance bonds for a period of several years after project completion, or simply performing required maintenance with public resources and billing the property owner for the work. This latter approach is particularly applicable if erosion or flooding problems result from the neglect. The excerpt below describes the approach to maintenance used by the City of Mountlake Terrace:

> "A maintenance schedule, including mowing frequency, shall be included in the plans. All harvested (or mowed) vegetation shall be removed from the swale as part of the regular maintenance

program. Inspections will be performed by City of Mountlake Terrace staff, is maintenance is required, the owner shall be notified in writing of the required action. If such notice fails to produce action on the part of the owner, public works crews shall perform maintenance and the owner will be charged all costs."

As in most endeavors, thoughtful planning can alleviate maintenance problems later on. Provision of an easy to reach, perhaps concrete-lined area at the head of the swale to catch sediment can prevent having to reseed or repair a channelized swale bottom. Adequate energy dissipation can also reduce problems with erosion and channelization.

Knowledge of the soils and groundwater regime on a site can give valuable clues about either soggy or arid conditions, both of which may influence the vigor and ease with which grass can be established. Provision for irrigation during the first summer season is important if seeding takes place in the spring.

Maintenance requirements should be considered before check dams are specified. What may seem like a water quality benefit may actually be a liability if it prevents regular mowing or maintenance. Rip-rap can plug with sediment, preventing flow of water and killing the grass. The fairly common practice of armoring the entire swale bottom with rip-rap needs to be challenged. If properly designed, armoring is not needed except for a very limited area at the head of the swale to provide energy dissipation. Rip-rapped swales also render mowing, and even maintenance, next to impossible.

At Metro and other agencies, it has been found useful to have grounds maintenance crews review landscaping and grounds designs before the final designs for capital projects are completed. A similar consultation among private sector parties would probably be equally useful.

AREAS FOR FURTHER STUDY

Hydraulic Residence Time

As in most studies, this investigation raised as many questions as it answered. One of the most promising areas for future research is to better establish the relationship between hydraulic residence time and treatment effectiveness so that more flexible basis for biofiltration facility design can be advanced. Such a study should be done on closely grouped sites having multiple swales designed to provide different water residence times. Grouping is important to assure that rainfall and runoff conditions are as similar as possible for all the swales, reducing confounding variables. The mechanics of performing such sampling are difficult and it is relatively expensive. However, the Unidata stage recorder used for this study performed better in the field than other flow instrumentation in common use. Reliable equipment greatly reduces the difficulty in collecting multiple samples. Another consideration in such a study is the impact on the site investigated. The provision of flumes, equipment barrels, and rain gages is obtrusive. In addition, the combination of flumes, water and sandbags (used to weight equipment tubing) is extremely enticing to youngsters who can recognize an ideal engineering opportunity when it presents itself. Such "assistance" was provided during the current study, causing some ideal storm samples to be rendered useless.

Manning's n Value for Mowed, Denser Grass

It is recommended that the research conducted in this project should be repeated for swales with relatively short, dense grass. The above investigation could possibly explore the performance and Manning's n for frequently mowed swales with higher grass densities at the same time that residence time considerations are explored. Manning's n for other vegetation types, such as wetland species, should also be investigated.

Maximum Width

The question of maximum swale width and criteria for effectiveness of swales wider than about 7 to 8 feet needs to be investigated. Design flexibility means little if proper field installation of those designs is not likely to occur. It may also be possible that use of plant material less densely spaced than grass but with more rigidity, such as red clover or native groundcovers, could overcome some of the channelization problems to which wide swales are susceptible.

Long-Term Pollutant Removal

The long-term effectiveness of biofiltration swales also needs to be rigorously investigated. There is some information from other parts of the country that over the long-term, swales do not perform as well as they might at first (Hartigan, personal communication). An ideal study would be to follow the swale investigated for this study periodically, say after 2, 5, and 10 years, to see how performance might vary as the swale ages. However, since the watershed would also be more densely developed, some means to account for this variable should be identified for this or any other time series study.

Swale Area Related to Watershed Area

Investigation of the correlation of swale treatment area with watershed area (or watershed impervious area) could result in a relatively simple to apply rule of thumb for provision of biofiltration swales for water quality protection, and should be investigated.

Nutrient Removal

Another important area for investigation is to enhance nutrient removal, particularly of phosphorus, in biofiltration swales. Among promising alternatives are the following:

- Investigate the effect of providing a section of bare clay soil as a mechanism to enhance the capture of dissolved phosphorus. The clay soil area should be near the end of the biofilter to minimize sedimentation on the clay surface, reducing its active treatment area.
- Investigate the use of alum, perhaps in solid form embedded in a rip-rap check dam, to facilitate removal of dissolved and bio-available phosphorus.

Both of these alternatives would require a control swale in addition to the test swale to best determine the effect of the treatment. Though not impossible, this need for paired swales would make finding a suitable site difficult.

It is recommended that these areas of investigation be considered a high priority for funding, particularly through the Centennial Clean Water Grant Program.

BIOFILTER DESIGN PROCEDURE AND EXAMPLE

Procedure

The procedures for swale and filter strip design are basically the same. The steps are given in full for swales, and notes are included to allow the procedure to be applied to filter strips as well. Unless specifically indicated, steps apply to both swales and filter strips.

Preliminary Steps (P)

P-1. Estimate runoff flow rate (Q) for the 6-month frequency, 24-hour duration storm.

Use a method acceptable to the local government and the situation, such as the method outlined in Chapter III-1 of Ecology's Stormwater Management Manual for the Puget Sound Basin, or an appropriate computer model.

Attempting to treat excessive flows in a biofilter will cause violations of the criteria stated above. For example, a Q approaching one cfs for common slopes would require a swale that violates one or more of the criteria on width, flow depth, or velocity. Moreover, achieving the hydraulic residence time specified would often require a very long swale for high values of Q. It is therefore recommended the ways be investigated to lower the design flow when an initial estimate is in the vicinity of 1 cfs or higher, if a swale is the anticipated form of biofilter (filter strips can accept higher flows if adequate land is available). Possibilities include dividing the flow among several swales, installing detention to control release rate upstream, and reducing the developed surface area to reduce runoff coefficient and gain space for biofiltration.

P-2. Establish the slope of the proposed biofilter. For guidance refer to Provisions Applying to Swales and Filter Strips (numbers 10-12) above.

P-3. Select a vegetation cover suitable for the site. For guidance refer to Provisions Applying to Swales and Filter Strips (numbers 3-5) above.

Design for Biofiltration Capacity (D)

There are a number of ways of applying the design procedure introduced by Chow (1959). These variations depend on the order in which steps are performed, what variables are established at the beginning of the process and which ones are calculated, and what values are assigned to the variables selected initially. The procedure recommended here is an adaptation appropriate for biofiltration applications of the type being installed in the Puget Sound region. This procedure reverses Chow's order, designing first for capacity and then for stability. The capacity analysis emphasizes the promotion of biofiltration, rather than transporting flow with the greatest possible hydraulic efficiency. Therefore, it is based on criteria that promote sedimentation, filtration, and other pollutant removal mechanisms. Since these criteria include a lower maximum velocity than permitted for stability, the biofilter dimensions usually do not have to be modified after a stability check.

D-1. Establish the height of vegetation during the winter and the design depth of flow.

Maximizing height advances biofiltration and allows greater flow depth, which reduces the width necessary to obtain adequate capacity. However, if nutrient capture is the principal objective, vegetation should be mowed at the end of the growing season to minimize nutrient release. The design depth of flow should be at least 2 inches less than the winter vegetation height, and a maximum of 3 inches in swales and 0.5 inch in filter strips.

D-2. Select a value of Manning's n as follows:

Routine swales that will be mowed with some regularity (also use for routine emergent herbaceous wetland plant applications)—0.20.

Infrequently mowed swales—0.24.

When it is known that vegetation will be very dense—selected.

D-3. Select the swale shape. Skip this step in filter strip design.

Normally, swales are designed and constructed in a trapezoidal shape. The following steps also give formulas for parabolic, rectangular, and V-shapes. A parabolic shape best resists erosion, but is hard to construct. A rectangular shape should only be used in a very confined space. For a rectangular swale specify reinforcement for the side walls in conformance with the standards of the local government. Do not specify a V-shape; the formulas are given only for analysis of swales already in place.

D-4. Use Manning's Equation and first approximations relating hydraulic radius and dimensions for the selected shape to obtain a working value of a biofilter width dimension:

$$Q \cong \frac{1.49}{n} AR^{0.67} s^{0.5} \qquad \text{Eq. G-1}$$

Where: Q = design runoff flow rate (ft^3/s, cfs)

n = Manning's n (dimensionless)

A = Cross-sectional area (ft^2)

R = Hydraulic radius = A/wetted perimeter (ft)

s = longitudinal slope as a ratio of vertical rise/horizontal run (dimensionless)

Refer to Figure G-1 to obtain equations for A and R for the selected shape. In addition to these equations, for a rectangular shape:

$$A = Ty \qquad \text{Eq. G-2}$$

$$R = \frac{Ty}{T+2y} \qquad \text{Eq. G-3}$$

Where: T = width

y = depth of flow

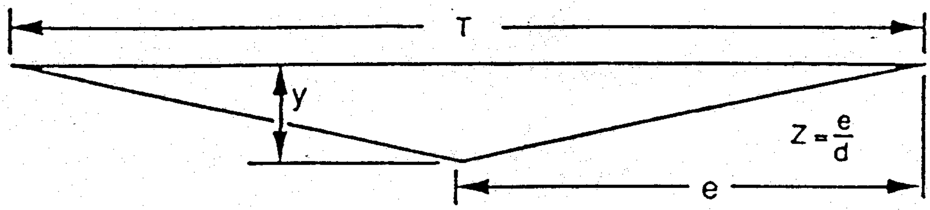
If these expressions are substituted in Eq. G-1 and solved for T (for previously selected y), the results are complex equations that are difficult to solve manually. However, approximate solutions can be found by recognizing that $T \gg y$ and $z^2 \gg 1$, and that certain terms are nearly negligible. The approximations for the various shapes are:

Parabolic:	$R \cong 0.67\,y$	Eq. G-4
Trapezoidal:	$R \cong y$	Eq. G-5
V:	$R \cong 0.5\,y$	Eq. G-6
Rectangular:	$R \cong y$	Eq. G-7

(Also use for filter strips.)

CHANNEL GEOMETRY

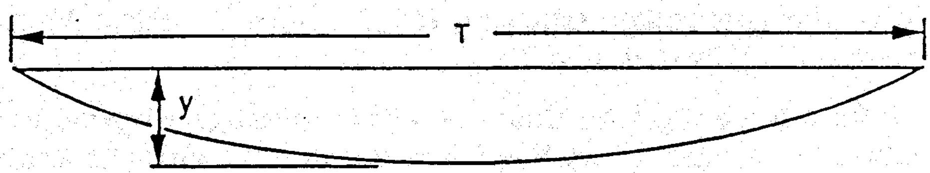
V - Shape



Cross-Sectional Area (A) = Zy^2
Top Width (T) = $2yZ$

Hydraulic Radius (R) = $\dfrac{Zy}{2\sqrt{Z^2+1}}$

Parabolic Shape

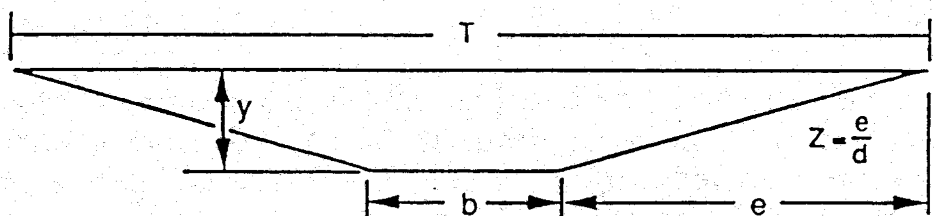


Cross-Sectional Area (A) = $\frac{2}{3}Ty$

Top Width (T) = $\dfrac{1.5A}{y}$

Hydraulic Radius (R) = $\dfrac{T^2y}{1.5T^2 + 4y^2}$

Trapezoidal Shape



Cross-Sectional Area (A) = $by + Zy^2$
Top Width (T) = $b + 2yz$

Hydraulic Radius (R) = $\dfrac{by + Zy^2}{b + 2y\sqrt{Z^2+1}}$

Figure G-1. Geometric Formulas for Common Swale Shapes (Livingston et al., 1984)

Making these substitutions and those for A from Figure G-1, and then solving for T gives:

Parabolic: $T \cong \dfrac{Qn}{0.76\, y^{1.67}\, s^{0.5}}$ Eq. G-8

Trapezoidal: $b \cong \dfrac{Qn}{1.49\, y^{1.67}\, s^{0.5}} - Zy$ Eq. G-9

V: $T \cong \dfrac{Qn}{0.47\, y^{1.67}\, s^{0.5}}$ Eq. G-10

Rectangular: $T \cong \dfrac{Qn}{1.49\, y^{1.67}\, s^{0.5}}$ Eq. G-11

(Also use for filter strips.)

For trapezoidal and V-shapes, select a side slope Z of at least 3.

Solve the appropriate equation for T and/or b. For a V-shape, check if $Z = T/2y$ is at least 3.

If b for a swale is greater than 8 ft, either investigate how Q can be reduced or arbitrarily set b = 8 ft and continue with the analysis. (b for a filter strip can be as great as uniform flow distribution can be assured.)

If b for a swale is less than 2 ft, set b = 2 ft and proceed.

D-5. Compute A using the appropriate equation from Figure G-1 or Eq. G-2.

D-6. Compute the flow velocity at design flow rate:

$V = \dfrac{Q}{A}$ Eq. G-12

This velocity should be less than 0.9 feet per second, a velocity that was found to cause grasses to be knocked from a vertical position, thus reducing filtration. If V > 0.9 feet per second, repeat steps P-1 through D-6 until this condition is met. A velocity lower than this maximum value is recommended because it will permit achieving the 9-minute hydraulic residence time criterion in a shorter biofilter (at V = 0.9 feet per second, a 486-ft long biofilter is needed for a 9-minute residence time and a 270-ft long biofilter for a 5-minute residence time, the absolute minimum). If the value of V suggests that a longer biofilter will be needed than space permits, investigate how Q can be reduced, or increase y and/or T (up to the allowable maximum values) and repeat the analysis.

D-7. Compute the swale length (L, ft):

$$L = (V)\ (t)\ (60\ \text{seconds/minute}) \qquad \text{Eq. G-13}$$

Where: t = hydraulic residence time (min)

Use t = 9 min for this calculation. If a biofilter length greater than the space permits results, follow the advice in step D-6. If all of these possibilities have been thoroughly checked and the space is still insufficient, t can be reduced, but to no less than 5 min.

If L < 100 ft results from this analysis, increase it to 100 ft, the minimum allowed. In this case it may be possible to save some space in width and still meet all criteria. This possibility can be checked by computing V in the 100 ft biofilter for t = 9 min, recalculating A from Eq. G-12 (if V < 0.9 feet per second), and recalculating T from one of the equations referenced in step D-5.

Check for Stability (Minimizing Erosion) (S)

The stability check must be performed for the combination of highest expected flow and least vegetation coverage and height.

Maintain the same units as in the biofiltration capacity analysis.

S-1. Unless runoff from events larger than the 6-month, 24-hour storm will bypass the biofilter, perform the stability check for the 100-year, 24-hour storm. Estimate Q for that event as recommended in Preliminary step 1.

S-2. Estimate the vegetation coverage ("good" or "fair") and height on the first occasion that the biofilter will receive flow, or whenever the coverage and height will be least. Attempt to avoid flow introduction during the vegetation establishment period by timing of planting or bypassing.

S-3. Estimate the degree of retardance from Table G-1. When uncertain, be conservative by selecting a relatively low degree.

Table G-1. Guide for Selecting Degree of Retardance (a)	
Average Grass Height (inches)	Degree of Retardance
Good	
>30	A. Very high
11-24	B. High
6-10	C. Moderate
2-6	D. Low
<2	E. Very low
Fair	
>30	B. High
11-24	C. Moderate
6-10	D. Low
2-6	D. Low
<2	E. Very low

(a) After Chow (1959). In addition, Chow recommended selection of retardance C for a grass-legume mixture 6 to 8 inches in height and D for the mixture 4 to 5 inches high. No retardance recommendations have appeared for emergent wetland species. Therefore, judgment must be used. Since these species generally grow less densely than grasses, using a "fair" coverage would be a reasonable approach.

S-4. Establish the maximum permissible velocity for erosion prevention (V_{max}) from Table G-2.

Table G-2. Guide for Selecting Maximum Permissible Swale Velocities for Stability*

Cover	Slope (percent)	Maximum Velocity (feet per second [m/s]): Erosion-Resistant Soils	Maximum Velocity (feet per second [m/s]): Easily Eroded Soils
Kentucky bluegrass Tall fescue	0-5	6 [1.8]	5 [1.5]
Kentucky bluegrass Ryegrasses Western wheat-grass	5-10	5 [1.5]	4 [1.2]
Grass-legume Mixture	0-5 5-10	5 [1.5] 4 [1.2]	4 [1.2] 3 [0.9]
Red fescue	0-5	3 [0.9]	2.5 [0.8]
Redtop	5-10	Not recommended	Not recommended

*Adapted from Chow (1959), Livingston et al. (1984), and Goldman et al. (1986).

S-5. Select a trial Manning's n. The minimum value for poor vegetation cover and low height (possibly, knocked from the vertical by high flow) is 0.033. A good initial choice under these conditions is 0.04.

S-6. Refer to Figure G-2 (from Livingston et al., 1984, after U.S. Soil Conservation Service, 1954) to obtain a first approximation for VR.

S-7. Compute hydraulic radius, using the V_{max} from step S-4:

$$R = \frac{VR}{V_{max}} \qquad \text{Eq. G-14}$$

S-8. Use Manning's Equation to solve for the actual VR:

$$VR = \frac{1.49}{n} R^{1.67} s^{0.5} \qquad \text{Eq. G-15}$$

S-9. Compare the actual VR from step S-8 and first approximation from step S-6. If they do not agree within 5 percent, repeat steps S-5 through S-9 until acceptable agreement is reached. If $n < 0.033$ is needed to get agreement, set $n = 0.033$, repeat step S-8, and then proceed to step S-10.

S-10. Compute the actual V for the final design conditions:

$$V = \frac{VR}{R} \qquad \text{Eq. G-16}$$

Check to be sure $V < V_{max}$ from step S-4.

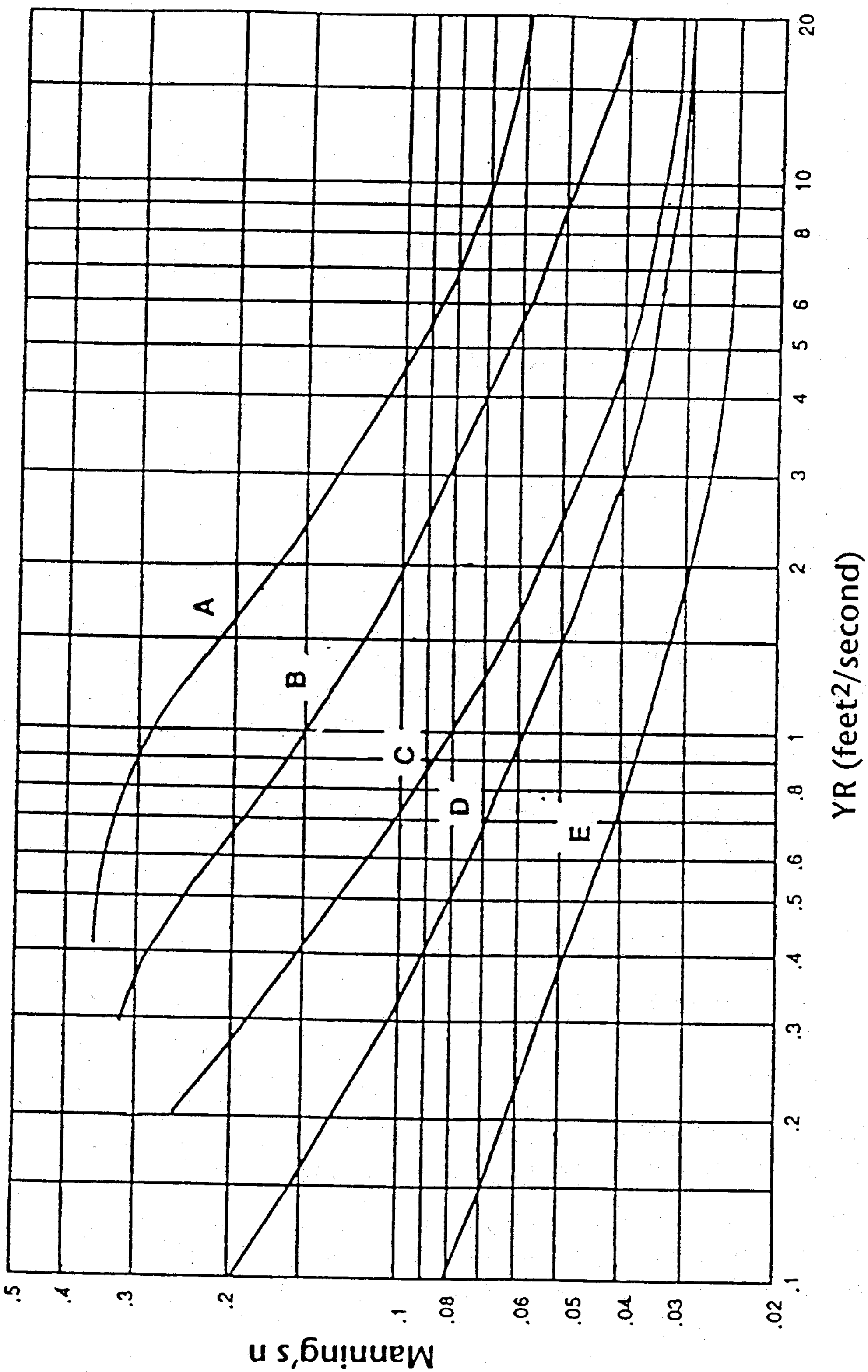
S-11. Compute the required A for stability:

$$A = \frac{Q}{V} \qquad \text{Eq. G-17}$$

S-12. Compare the A computed in step S-11 of the stability analysis with the A from the biofiltration capacity analysis (step D-5).

If less area is required for stability than is provided for capacity, the capacity design is acceptable. If not, use A from step S-11 of the stability analysis and recalculate channel dimensions (refer to Figure G-1 or Eq. G-2).

S-13. Calculate the depth of flow at the stability check design flow rate condition for the final dimensions (refer to Figure G-1 or Eq. G-2 and use A from step S-11 of the stability analysis).



Note: VR is the product of velocity and hydraulic radius

Figure G-2. The Relationship of Manning's n with VR for Various Degrees of Flow Retardance (A-E)

S-14. Compare the depth from step S-13 to the depth used in the biofiltration capacity design. Use the larger of the two and add 1 foot freeboard to obtain the total depth of the swale. Calculate the top width for the full depth using the appropriate equation. Skip this step in filter strip design.

S-15. Make a final check for capacity based on the stability check design storm and maximum vegetation height and cover (this check will ensure that capacity is adequate if the largest expected event coincides with the greatest retardance).

Use Equation G-1, the Manning's n selected in step D-2, and the calculated channel dimensions, including freeboard, to compute the flow capacity of the channel under these conditions.

If the flow capacity is less than the stability check design storm flow rate, increase the channel cross-sectional area as needed for this conveyance. Specify the new channel dimensions.

Completion Steps (C)

C-1. Review all of the Criteria and Guidelines for Biofilter Planning, Design, Installation, and Operation above and specify all of the appropriate features for the application.

EXAMPLE (BIOFILTRATION SWALE)

Preliminary Steps

P-1. Assume that Q for the 6-month, 24-hour storm was established by one of the recommended procedures to be 0.5 cfs.

P-2. Assume the slope is 2 percent

P-3. Assume the vegetation will be one of the recommended grass mixes.

Design for Swale Biofiltration Capacity

D-1. Set the winter grass height at 5 inches and design flow depth at 3 inches (0.25 ft).

D-2. Use n = 0.2.

D-3. Base the design on a trapezoidal shape.

D-4. Eq. G-9: $b \cong \frac{Qn}{1.49\ y^{1.67}\ s^{0.5}} - Zy$

$Q = 0.5$ cfs $\quad y = 0.25$ ft

$n = 0.2 \quad s = 0.02$

$b \cong 4$ ft

D-5. Figure G-1: $T = b + 2yZ \quad A = by + Zy^2$

$T = 5.5$ ft $\quad A = 1.19\ ft^2$

D-6. Eq. G-12: $V = \frac{Q}{A}$

$V = 0.42$ feet per second < 0.9 feet per second (OK)

D-7. Eq. G-13: $L = (V)\ (t)$ (60 seconds/minute)

For $t = 9$ min, $L = 227$ ft

Since b is less than the maximum value, it may be possible to reduce L by increasing b.

For example, if L = 180 ft is desired:

Eq. G-13: $V = \frac{L}{60t} = 0.33$ feet per second

Eq. G-12: $A = \frac{Q}{V} = 1.52\ ft^2$

Figure G-1: $b = \frac{A - Zy^2}{y} = 5.33$ ft

Check for Channel Stability

S-1. Base the check on passing the 100-year, 24-hour storm runoff flow through the swale. Assume that Q for that storm was established by one of the recommended procedures to be 1.6 cfs.

S-2. Base the check on a grass height of 3 inches with "fair" coverage (lowest mowed height and least cover, assuming flow bypasses or does not occur during grass establishment).

S-3. Table 6-1: Degree of retardance = D.

S-4. Assume soils analysis has established soils as erosion resistant.

Table G-3: $V_{max} = 5$ feet per second

S-5. Select trial $n = 0.04$

S-6. Figure G-2: $VR = 3\ ft^2/s$

S-7. Eq. G-14: $$R = \frac{VR}{V_{max}}$$

$R = 0.6\ ft$

S-8. Eq. G-15: $$VR = \frac{1.49}{n} \quad R^{1.67}\ s^{0.5}$$

$VR = 2.24\ ft^2/s$

S-9. VR from step S-8 < VR from step 6 by > 5 percent.

Select new trial $n = 0.038$

Figure G-2: $VR = 4\ ft^2/s$

Eq. G-14: $R = 0.8\ ft$

Eq. G-15: $VR = 3.81\ ft^2/s$ (within 5 percent of VR = 4)

S-10. Eq. G-16: $$V = \frac{VR}{R} = \frac{3.81}{0.8}$$

V = 4.76 feet per second < 5 feet per second (OK)

S-11. Eq. G-17: $$A = \frac{Q}{V} = \frac{1.6}{4.76} = 0.34$$

S-12. Stability $A = 0.34\ ft^2$ from step S-11 < capacity $A = 1.19$ or $1.52\ ft^2$ from step D-5 or D-7 (OK).

If stability A > capacity A, it will be necessary to select new trial sizes for width and flow depth (based on space and other considerations), recalculate A, and repeat steps S-11 and S-12.

S-13. Figure G-1: $$y = \frac{-b \pm (b^2 + 4ZA)^{0.5}}{2Z}$$ (quadratic equation solution)

For b = 5.33 ft, y = 0.06 ft (positive root)

S-14. Greater depth is 0.25 ft, which was the basis for the biofiltration capacity design (step 1). Add 1 ft freeboard to that depth.

Total channel depth = 1.25 ft

Top width = b + 2yZ = 5.33 + (2)(1.25)(3) = 12.83 ft

S-15. $Q = \frac{1.49}{n} AR^{0.67} s^{0.5}$

$A = by + Zy^2$

For b = 5.33 ft and y = 1.25 ft, A = 11.35 ft^2

$R = \frac{by + Zy^2}{b + 2y\,(Z^2 + 1)^{0.5}}$

For b = 5.33 ft and y = 1.25 ft, R = 0.86 ft

s = 0.02 n = 0.2

Q = 10.8 cfs > 1.6 cfs (OK)

APPENDIX G-2
SIZING DETENTION BMPS FOR RUNOFF TREATMENT

Appendix G-2
Guidance for Sizing Detention BMPs

This appendix provides guidance for sizing detention BMPs Nos. 45-51, described in Section 5.5 of this Handbook.

Permanent BMPs that are not intended to detain runoff volume, such as and filters and compost stormwater filters, should be sized according to the fact sheets in Chapter 5. Biofiltration swales (BMP #38) should be sized using guidance in Appendix G-1. Facilities such as wet ponds, wetlands, and vaults, will vary in size depending on the volume of runoff from their contributory areas. These detention facilities should be sized according to the following rules of thumb.

1. The water surface area in the detention facility shall be a minimum of one percent of the impervious area in the drainage basin contributing to the facility.

2. The volume of the detention facility shall be a minimum of the total volume of runoff from 1/3 of the 2-year, 2-hour design storm.

3. An overflow or other mechanism must be included and of sufficient size to meet local agency guidelines for flood control.

4. The deepest part of any detention facility should not exceed 6 feet. Depths greater than this tend to become anoxic and may release nutrients in a dissolved form from deposited sediments, among other problems.

5. When possible, the depth of permanent pools should be at least three feet to avoid resuspension of sediments when water flows through the facility.

The facilities which include vegetation as an integral component of the facility, such as wetlands, have certain maximum depth limitations. This may necessitate a larger surface area for the facility in order to achieve the required volume. These special depth requirements are listed in the fact sheets in Chapter 5.

APPENDIX G-3

BASIC REQUIREMENTS FOR STORMWATER SITE DESIGN

Appendix G-3
Basic Requirements for Stormwater Site Design

The following are two categories of requirements: those that apply to all new and redevelopment projects, and those that just apply to projects which will discharge directly to a waterbody.

Requirements which apply to all new and redevelopment projects

Preserve Natural Drainage Systems

Preserve and maintain natural drainage systems and allow discharges from the site to occur at the natural location. Do not disturb natural vegetated buffers along streams, unless the vegetative buffer is part of the water quality treatment facility.

Floodplains

Consult the Idaho Department of Water Resources (IDWR) if the project is within a designated floodplain or below the mean highwater level.

Subsurface Disposal and Infiltration

In areas that have poorly drained soil conditions and/or a high water table, deep subsurface disposal systems, including dry wells and injection wells, are not encouraged or recommended in most cases. If dry wells or injection wells are constructed, they must be permitted with the IDWR. Additionally, due to the water table and intensive maintenance requirements, porous pavement is not recommended. Facilities such as infiltration trenches and basins could be approved, if it is demonstrated by the developer that the site can handle infiltration. This will require site-specific testing to determine the infiltration rate at the site. In general, the infiltration rate should be greater than 0.4 inches/hour. See BMP fact sheets #43 and #44 in Section 5.4 of this Catalog for additional information about application and design of trenches and basins.

Operation and Maintenance

Provide an operation and maintenance schedule for the proposed stormwater BMPs, and indicate the party (or parties) responsible for maintenance after construction is complete. Use the BMP fact sheets in Chapters 4 and 5 to determine the maintenance needed for each BMP type.

Prepare a maintenance plan that outlines the scope of activities, schedule, and responsible parties for inspecting and maintaining the facility. Vegetation, sediment management, access and safety are primary issues to be addressed by any maintenance plan. In general, it is important to schedule maintenance around sensitive wildlife and vegetation seasons. Due to expected pollutants,

most industrial site facilities will generally require more frequent maintenance than facilities on commercial or residential sites. See individual BMP fact sheets in the Catalog for other scheduling specifics.

Plantings may require a number of control practices during their period of establishment, which is generally the first one to two years after installation. Irrigation may be required during establishment or during times of drought. Mulching to retain top-soil, heat and moisture, as well as inhibiting weed growth, may be needed. Avoid using fertilizers, herbicides or pesticides for vegetation maintenance or insect control if possible, or use the products sparingly in a manner that minimizes discharge of these pollutants to stormwater runoff. Temporary fencing may also be needed to protect seedlings from foraging animals. See Appendix F for additional details regarding vegetative management.

In the maintenance plan, it may be necessary to make provisions for testing of sediments removed during maintenance activities. This is particularly important when it is suspected, due to the nature of the activity on the site or location of the site, that levels of pollutants in sediments may exceed allowable threshold limits for disposal in a municipal landfill. For example, the site may be located in an area with a history of upstream spills. Testing could include parameters such as oil and grease, metals (e.g., lead, zinc and cadmium), and/or nutrients such as phosphorus, depending on the situation. Store and dispose of sediments removed from stormwater detention facilities in accordance with safe management practices specified by applicable local, state, and federal regulations.

Finally, ensure that the design addresses maintenance access and safety issues.

Requirements which apply to all new and redevelopment sites that drain directly to a stream, creek, lake or other water body

Before developing the site plan further, check with the responsible authority to learn about any special restrictions or permitting that may be required for the new site discharge, including carrying capacity of the receiving system. If site discharges directly to:

- piped storm drain system—within the city limits, contact the city; in the unincorporated areas, contact the County
- irrigation ditch canal—contact the responsible irrigation district or ditch company: see contact sheet at the front of the Catalog
- state highway ditch—contact ITD
- other local road ditch—within the city limits, contact the city; in the unincorporated areas, contact the County

- any lake or reservoir—contact the regional IDEQ office, Idaho Department of Fish and Game (IDFG), and EPA Region 10
- a stream—see basic requirements for streambank erosion *below*; then contact a regional IDEQ office, the IDFG, and/or EPA Region 10
- natural wetlands—see basic requirements for wetlands below. Note that dredging, filling, utilities work, and construction in wetlands hydraulically connected to the waters of the United States is governed by Section 404 Permitting administered by the Army Corps of Engineers.

Streambank Erosion Control

For direct Stormwater discharges to streams, control streambank erosion by *limiting* the peak rate of runoff from the site to 50 percent of the existing condition 2-year, 24-hour design storm and *maintaining* the existing condition peak runoff rate for the 10- and 100-year, 24-hour design storms.

Stormwater treatment BMPs should not be built within a natural vegetated buffer, unless the vegetative buffer is part of the stormwater treatment by way of providing infiltration.

Wetlands

In situations where stormwater discharges directly or indirectly to existing wetlands follow these guidelines:

(a) Contact the Corps of Engineers and the nearest Idaho DEQ regional office prior to commencing any work within an area suspected to be wetlands.

(b) Stormwater discharges to wetlands must be controlled and treated to the extent necessary to meet the State Water Quality Standards, as appropriate.

(c) Discharges to wetlands should maintain the flows of existing site conditions to the extent necessary to protect the characteristic uses of the wetland. Prior to discharging to a wetland, alternative discharge locations should be evaluated, and natural water storage and infiltration opportunities outside the wetland should be maximized.

(d) Constructed wetlands that are intended to mitigate the loss of wetland acreage, function and value and can easily integrate stormwater treatment may be considered for use as a stormwater runoff BMP. Discharges from constructed wetlands to waters of the state (including discharges to natural wetlands) are regulated under Water Quality Standards (WQS) and Water Treatment Rules (WTR), IDAPA Sections 16.01.02.080; 16.01.02.400.04; 16.01.02.350; 16.01.02.800

(e) A natural wetland may be considered a site for a treatment system without conflicting with federal laws as long as the design of the treatment system does not change the "function and design" of the wetland

(f) Dredging, filling, utilities work, and construction in wetlands hydraulically connected to the waters of the United States is governed by Section 404-Permitting, administered by the Army Corps of Engineers and Section 401-Certification, administered by the DEQ.

Exceptions to Basic Requirements

Exceptions to the basic requirements listed above may be granted by the local permitting authority prior to approval and construction of a new development project provided that the exception addresses the following:

- The exception provides equivalent environmental protection and is in the overriding public interest; and that the objectives of safety, function, environmental protection, preserving the aesthetic quality of the project site and facility maintenance, based upon sound engineering, are fully met;

- The granting of the exception will not be detrimental to the public health and welfare, nor injurious to other properties in the vicinity and/or downstream, and to the quality of waters of the state; and

- The exception is the least possible exception that could be granted to comply with the intent of the basic requirements given above.